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EVALUATION OF A PHYSICALLY BASED INLAND WATER PROCESSOR FOR MERIS DATA

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ABSTRACT

The physically based Modular Inversion & Processing System (MIP) is used in a processing chain for inland water constituent retrieval from MERIS level 1B full resolution data. Reformatting, data import, water/land masking, atmospheric correction and water constituent retrieval are fully automatic, in order to allow the efficient analysis of large data. The adequacy of a first parameterisation for Lake Constance is tested for two datasets acquired in spring and summer. Pelagic, littoral and a Rhine estuary site are considered to study the results' adequacy under varying water constituent concentrations and atmospheric influences. The results will be used to improve the overall accuracy for the processing of a time series of Lake Constance, and to individualise the processing chain to the optical properties of other Swiss Lakes.

INTRODUCTION

Monitoring of water quality in lakes is required as an integral part of water resource management, in order to guarantee the sustainable use of water and to track the effects of anthropogenic influences. Simultaneously, adequate monitoring is required to report the effects achieved by management programs. In situ water quality monitoring of the large glacial and fluviglacial Swiss lakes was established in the 1950s and 1960s. It takes into account a broad range of water quality parameters at decent temporal resolutions, but is limited in the spatial dimension. The MERIS instrument onboard ENVISAT offers increased potential to support established monitoring programs by means of remote sensing, thus complement them with spatial information. However, MERIS level 2 water constituent products were found not to be accurate for inland waters (1). Remarkably improved results were achieved by customizing retrieval algorithms to lake specific properties (2,3).

MIP was used for experimental water constituent retrieval of Lake Constance and other inland water bodies with many sensors. In order to use MIP operationally, we built a pre-processing chain that allows for the use as an automatic processor for MERIS level 1B full resolution data (4). Single lake clippings are extracted from MERIS scenes and used as input for the physically based Modular Inversion & Processing System (MIP) (5,6). MIP performs image based aerosol retrieval and atmospheric correction in advance of the water constituent retrieval, and is therefore well suited for use in an automatic processor. We used MIP in a simple, non-iterative batch mode, in order to keep the processing time within about a minute per scene. A specific parameterisation of the processor is needed for each lake. The first set of parameters was optimised for Lake Constance, where extensive knowledge on specific inherent optical properties is available (6,7). The general applicability of the processor and the sensitivity of each parameter were examined also with Lake Constance (8). In this work, the algorithms performance with the current parameterisation is investigated under varying spatial and temporal situations.

INPUT IMAGERY

MERIS level 1B full resolution datasets were delivered in two image formats. Both 2241 square pixel scenes and 1153 square pixel quarter scenes ("imagettes") are processed. All data is acquired at a nominal ground resolution of 260 × 290 m. The data are geolocated but not geometrically corrected. Time of acquisition, geolocation and observation angles are needed as input for

MIP and are therefore automatically extracted from each scene's metadata. Furthermore, the pixel flag information is extracted to an MIP structure to retain information on data quality, although the sun glint risk flags were found not suitable for use with inland waters. Numerous datasets covering the Swiss midland and prealpine lakes in the years 2003-2006 were collected in an archive, assuring approximately biweekly resolution. The data is used for the calculation of time series for Lakes Constance, Geneva and Neuchatel, whereas the spatial resolution of MIP is barely sufficient for the investigation of smaller lakes by means of MIP.

For IDL preprocessing and MIP processing, the proprietary PDS files need conversion to a generic format. The batch executable "pds2hdf" contained in ESA's free EnviView application was found to cut 2241 square pixel image data in smaller segments of 1153 pixel imagette size during conversion to HDF. Therefore, "pconvert" from the BEAM toolbox is used for conversion of both types of datasets to dimap format. Specific IDL routines are then used to apply the scene specific radiance scaling factors, to extract single image clippings for each lake (Figure 1) and to complement each clipping with corresponding metadata. The output is saved in MIP-readable BIL-files and a specific input file structure for MIP processing modules.

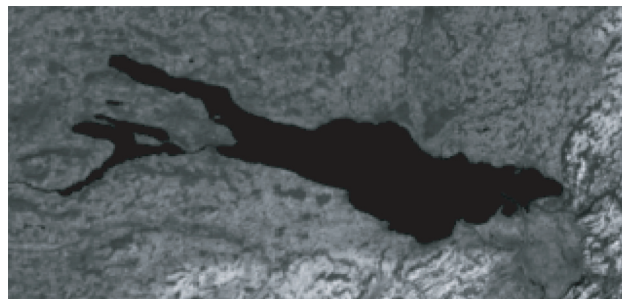


Figure 1: Lake Constance clipping, acquired 17 April 2003, as channel 14 (885 nm) greyscale.

MIP PROCESSING

MIP consists of several modules for the retrieval of water-related parameters from remote sensing data (5,6). The two modules used in this work are simple (meaning non-iterative) batch executables that accomplish land/water masking and atmospheric correction, and water constituent retrieval, respectively. Thus, the performance is much faster than when processing the two modules iteratively (3). The water constituents retrieved are chlorophyll a (chl-a) and suspended matter (sm), while yellow substance concentration is held constant. MIP is used with a main radiative transfer database, built from simulation results of a coupled, plane-parallel atmosphere-water model, by use of the finite element method (FEM) (9). This main RT database contains a variety of optical properties for atmosphere and water at high spectral resolution and for a large set of geometries. For each image clipping to be processed, a mission specific RT database is extracted, accounting only for sensor parameters and for the image specific observation and illumination geometry (Figure 2).

An adequate aerosol type (continental, maritime, rural) and aerosol optical thickness (AOT, at 550 nm) has to be estimated as input for land/water masking. The thresholds for land/water discrimination are set according to typical values of subsurface reflectance, regarding different channels between 680 and 800 nm, and performing a first-guess atmospheric correction with fixed initial values of AOTs. The output files contain unchanged at-sensor radiances from respective input dataset above water, and zero values above land.

To correct for atmospheric influence, the parameters to be estimated are again aerosol type and the spectral backscattering coefficient and average concentrations of sm. Furthermore, a NIR reference channel has to be chosen. Subsurface irradiance reflectance is calculated according to assumed water optical properties. The AOT for the estimated aerosol type is then retrieved pixelwise, calculating the path-scattered radiance from the modelled subsurface reflectance and the measured at-sensor radiance in the NIR reference channel. With the AOT retrieved in that way, an atmospheric correction of the water masked pixels is performed for all channels. The output is a

so-called pseudo albedo, a subsurface irradiance reflectance not corrected for the directionality of the underwater light field (Q-factor) (5). The atmospherically corrected channels can then be chosen for water constituent retrieval.

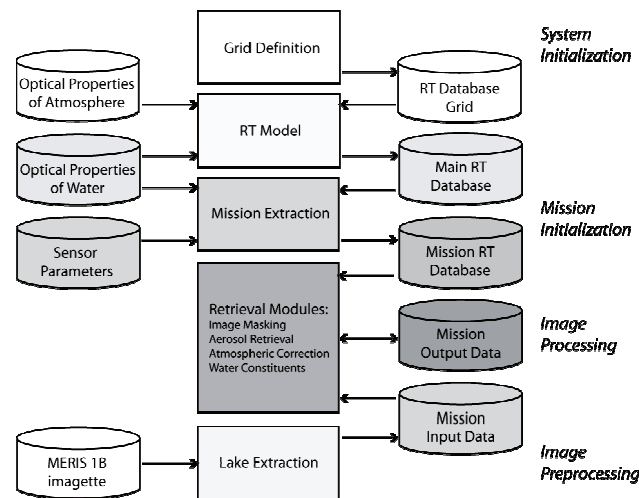


Figure 2: Flow chart of image preprocessing (lower workflow) and MIP processing (upper workflow). Dark shading indicates work progress (modified from (3)).

The number and weighting of channels used in the model/data fit can be defined prior to the retrieval of chl-a and sm. Initial values, maximum, minimum and tolerance thresholds for each parameter's concentration are set according to the range of concentrations occurring in a specific lake. By means of a Simplex algorithm, the simulated subsurface reflectance for varying constituent concentrations is then fitted with the subsurface reflectance from atmospherically corrected image pixels. The Q-factor correction is applied iteratively during the optimization procedure, to meet the changing concentrations of water constituents at the specific sun-observer geometry (6).

The optimisation of processing parameters for Lake Constance (Table 1) was mainly an iterative approximation of processing results to previous optical measurements (7) and model calculations (8). It is currently being improved with spectroradiometric subsurface reflectance measurements acquired in April 2007. With similar data to be measured on Lake Geneva and Neuchatel, specific processing parameterisations for these lakes will follow.

Table 1: Set of parameters optimised for analysis of Lake Constance (8).

Process	Parameter	Value
<i>Atmospheric Correction</i> (TOA radiance to subsurface reflectance)	Aerosol Model	Maritime
	AOT Reference Band	14 (855 nm)
	TSM a priori assumption	1.0 g/m ³
	Scattering coefficient	Kallio et al. (10)
<i>Water Constituent Retrieval</i> (Q-correcting subsurface reflectance)	Channel weighting	2 (442 nm): 0.2 3-7: 1.0 8 (681 nm): 0.5
	Maximum threshold	chl-a: 20 mg/m ³ sm: 10 g/m ³
	Minimum threshold	chl-a: 0.8 mg/m ³ sm: 0.5 g/m ³
	Tolerance threshold	chl-a: 0.5 mg/m ³ sm: 0.3 g/m ³
<i>Sensor Recalibration factor</i> (applied due to experiences in earlier work with MERIS data in MIP)	Channel gain factor	0.98 in channels 1 and 2 1.02 in channel 6 (620 nm)

In order to make the water quality monitoring data measured as 20 m depth sample by IGKB (Internationale Gewässerschutzkommission für den Bodensee) comparable to the chl-a values determined by MIP, the following empirical correlation between optically detectable and vertically sampled was used (6):

$$chl_a(0-2m) = chl_a(0-20m)^{\frac{1}{0.87}}$$

RESULTS

Two image clippings of Lake Constance were used for the assessment of the algorithms performance. For each scene, 3 sites were extracted to investigate the fit of image derived subsurface reflectances after atmospheric correction and subsurface reflectance modelled for the resulting constituent concentrations. The first site in the lake's centre corresponds to the water quality sampling site Fischbach-Uttwil and represents the situation in pelagic areas. The second site is located near Friedrichshafen in a shallow water area on the northern shore of Lake Constance, representing the littoral zone. The third site near the Rhine estuary allows for an estimation of the influence of varying sm concentrations.

In the chl-a map of 17 April 2003 (Figure 3), strongly increasing concentrations towards the shore indicate an influence of atmospheric and bottom effects on the water constituent retrieval. This shows one current limitation of the method, which can't account for reliable results within 1-2 kilometres from the shore, mainly due to adjacency effects. The sm map calculated for the same image shows generally low concentrations with a significant increase in the Rhine estuary.

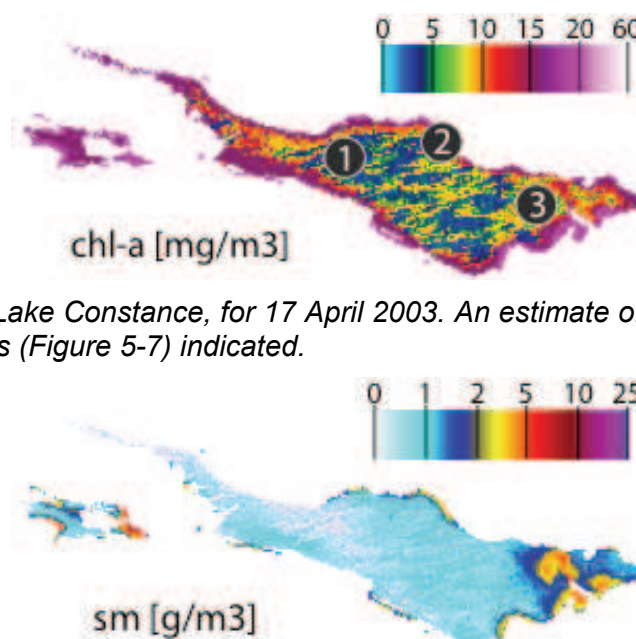


Figure 3: Chl-a map of Lake Constance, for 17 April 2003. An estimate of the overall retrieval quality is given for the 3 sites (Figure 5-7) indicated.

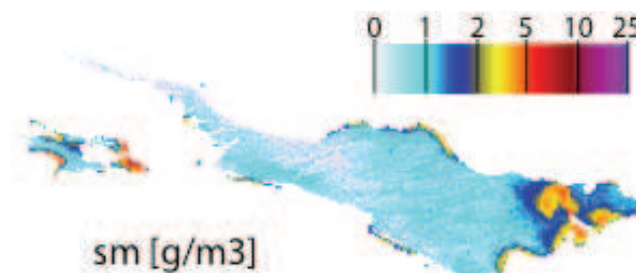


Figure 4: Sm map of Lake Constance, for 17 April 2003.

In the pelagic zone, concentrations of 3.29 mg chl-a/m³ and 0.55 g sm/m³ are calculated from the MERIS image (Figure 5). This result is backed by water quality monitoring data measured at Fischbach-Ueberlingen a week before and five days after image acquisition, which indicate an increase of chl-a from 1.99 to 4.22 mg/m³. The overall fit of input and model is satisfactory, although the a priori sm concentration value assumed for atmospheric correction is about twice the value retrieved.

Chl-a and sm for 17 April 2003 show strong spatial inhomogeneities around site 2, indicating adjacency effects and possibly bottom effects (Figure 3). Accordingly, the model/input fit for the littoral zone agrees poorly (Figure 6), especially at short wavelengths, where the error rate due to atmospheric correction inaccuracies increases. The resulting, unrealistic value of 20 mg chl-a/m³ equals the maximum threshold of the algorithm (Table 1). Sm concentration is 2.95 g/m³.

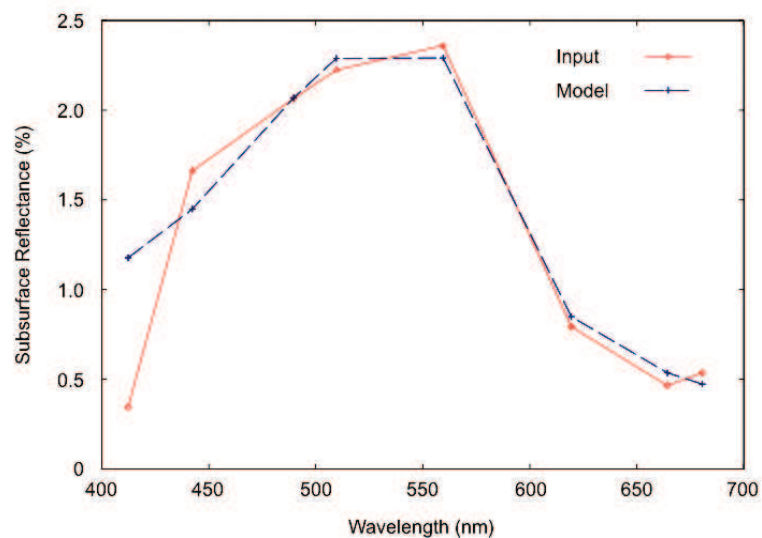


Figure 5: Input/model fits for the MERIS scene acquired 17 April 2003, site 1 (pelagic).

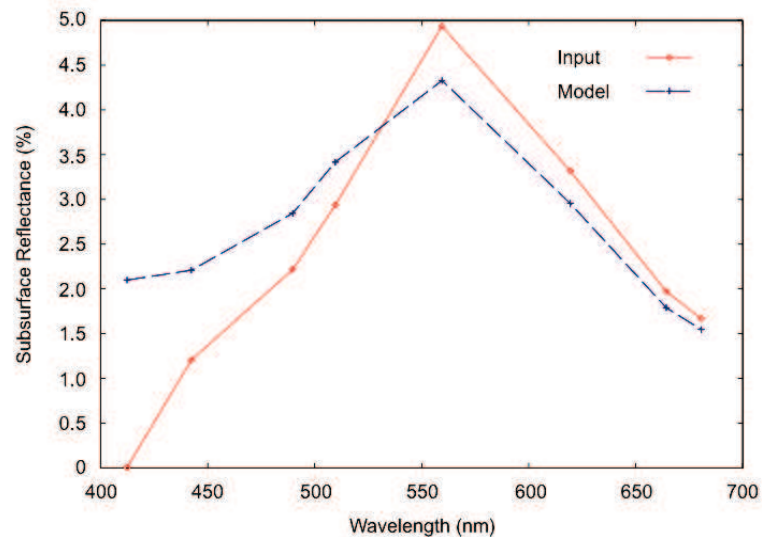


Figure 6: Input/model fits for the MERIS scene acquired 17 April 2003, site 2 (littoral).

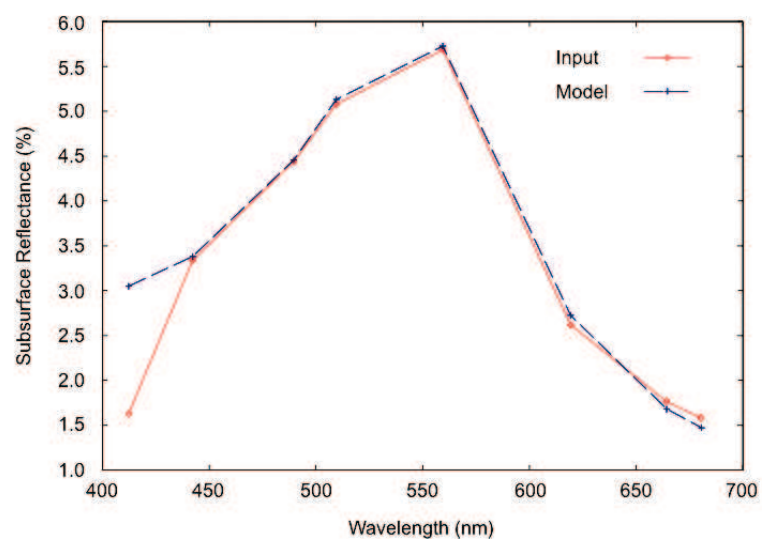


Figure 7: Input/model fits for the MERIS scene acquired 17 April 2003, site 3 (Rhine estuary).

Surprisingly, the best fit of input and model is achieved for site 3 near the Rhine estuary. The resulting sm concentration of 1.68 g sm/m^3 is in good agreement with values derived from Secchi-depth measured by IGKB (3). These sm concentrations can still be considered in the range of the a priori assumption (1 g sm/m^3 , Table 1), while sm values up to 5 g sm/m^3 in the plume again lead to less adequate results. Chl-a values of 7.64 mg/m^3 at site 3 seem rather high but remain unvalidated.

In the chl-a map of 3 July 2005 (Figure 8), the strong increase of concentration towards the shore is not visible. The spatial patterns are larger than on 17 April 2003. Chl-a concentrations are slightly lower, but the sm concentrations (Figure 9) are a multiple of the values indicated for the previous scene (Figure 4), so that the Rhine plume is hardly visible.

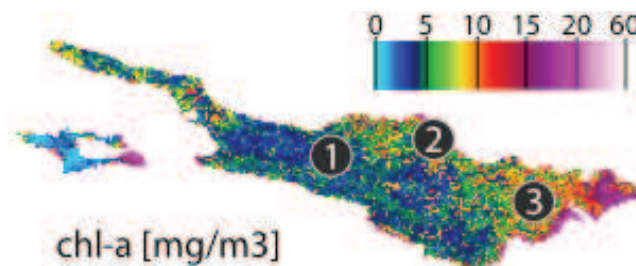


Figure 8: Chl-a map of Lake Constance, for 3 July 2005. An estimate of the retrieval quality is given at the 3 sites (Figure 10-12) indicated.

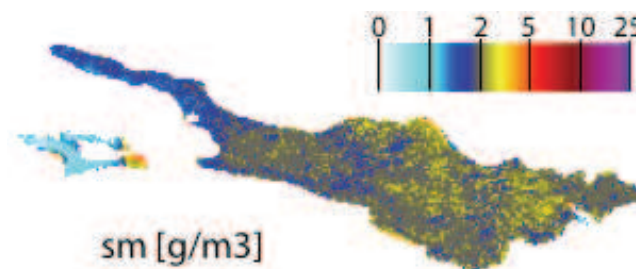


Figure 9: Sm map of Lake Constance, for 3 July 2005.

In the pelagic zone, values of $5.21 \text{ mg chl-a/m}^3$ and 1.95 g sm/m^3 are calculated at a moderate model/input fit (Figure 10). A concentration of $3.93 \text{ mg chl-a/m}^3$ was measured by IGKB on the subsequent day. Since the larger area around site 1 is in better agreement with these results, it seems reasonable to average the results spatially and thereby account for spatial inhomogeneities.

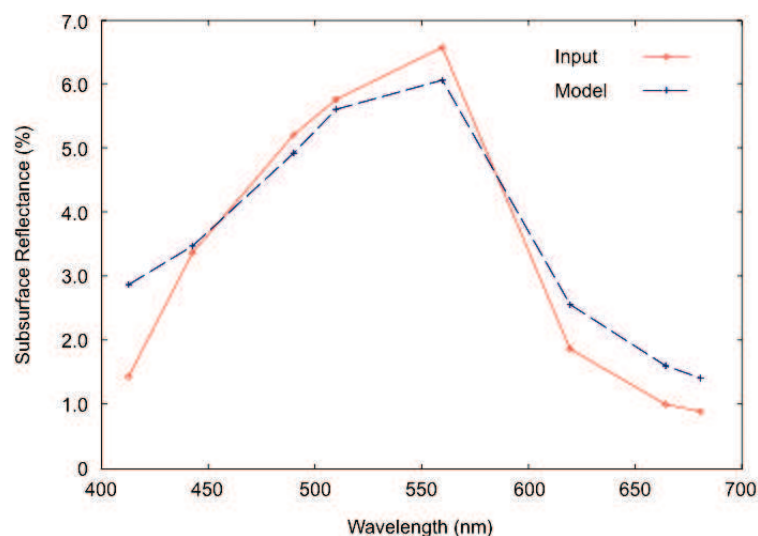


Figure 10: Input/model fits for the MERIS scene acquired 3 July 2005, site 1 (pelagic).

As before, the agreement of model and input is rather weak in the littoral zone (Figure 11). The retrieved 9.41 mg chl-a/m³ and 2.39 g sm/m³ are not quite as far out of scope though, since the atmospheric correction performs generally better than on 17 April 2003.

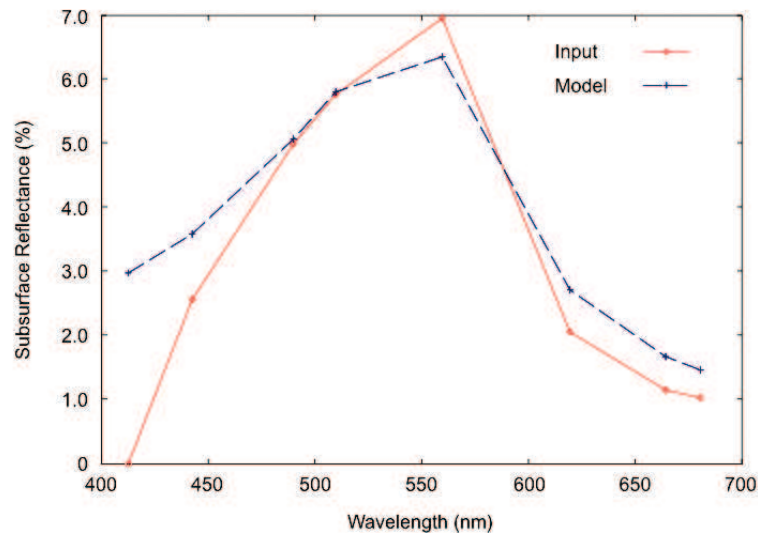


Figure 11: Input/model fits for the MERIS scene acquired 3 July 2005, site 2 (littoral).

For the Rhine estuary, a chl-a concentration of 5.59 mg/m³ and 1.58 g sm/m³ is calculated. These low suspended matter concentrations near the main inflow of Lake Constance indicate that the high concentration of sm in the pelagial zone is of organic origin, which seems not improbable at this time of the year. But with large residuals in the input/model fit, the results remain uncertain.

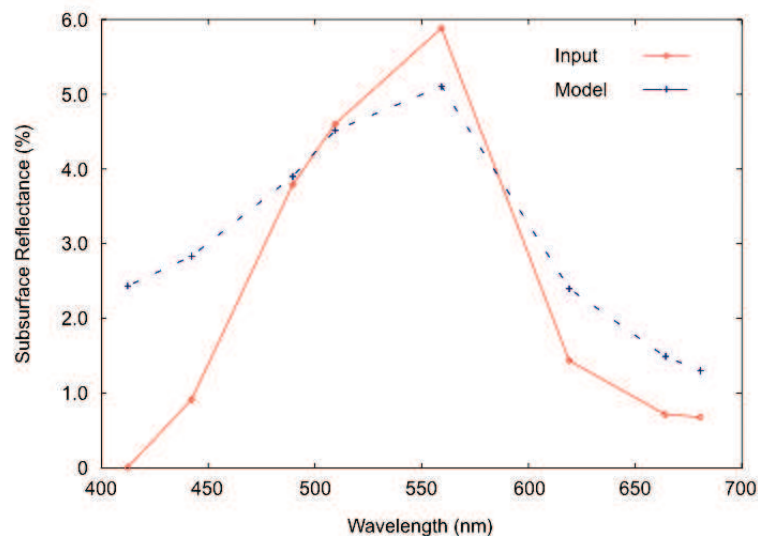


Figure 12: Input/model fits for the MERIS scene acquired 3 July 2005, site 3 (Rhine estuary).

OUTLOOK

The MERIS inland water processor for MIP needs some refinement, as we found the algorithm to be more sensitive to observation geometry than assumed. Simultaneously, the acquisition of specific inherent optical properties in other lakes will allow for the portability of the processor to other lakes. Further improvements that bear potential for more adequate processing results are mainly regarding atmospheric correction and the elimination of adjacency effects. A sun glint risk flag as found erroneous in the MERIS metadata could help to further improve the reliability of processed image pixels.

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